The Carbon Abundance and $^{12}C/^{13}C$ Isotopic Ratio in the Atmosphere of Arcturus from 2.3 micron CO Bands

Ya. V. Pavlenko*

July 24, 2008

Abstract

Absorption lines of the ^{12}CO and ^{13}CO molecular bands ($\Delta v = 2$) at 2.29 – 2.45 micron are modelled in spectrum of Arcturus (K2III). We compute a grid of model atmospheres and synthetic spectra for giant of Teff = 4300, log g = 1.5, and the elemental abundances of Peterson et al. (1993), but abundances of carbon, oxygen and the carbon isotopic ratio, $^{12}C/^{13}C$ are varied in our computations. The computed spectra are fitted to the observed spectrum of Arcturus from the atlas of Hinkle et al. (1995). The best fit to observed spectrum is achieved for log N(C) = -3.78 $\pm$ 0.1, $^{12}C/^{13}C = 8 \pm 1$. A dependence of the determined $^{12}C/^{13}C$ vs. log N(C) and log N(O) in atmospheres of red giants is discussed.

*Main Astronomical Observatory, National Academy of Sciences of Ukraine, 27 Zabolotnogo, Kiev, 03680 Ukraine; http://www.mao.kiev.ua/staff/yp

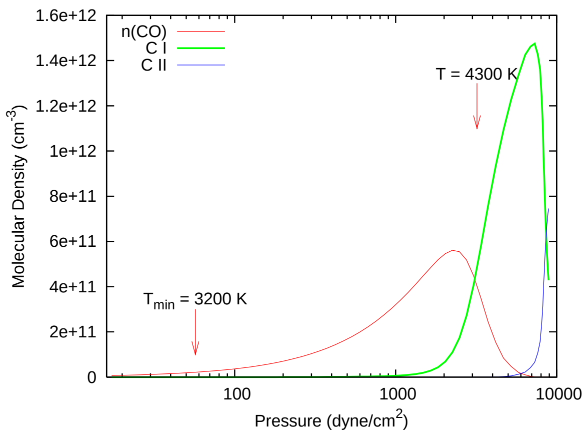

Figure 1: Molecular densities of CI, CII and CO in the atmosphere with Teff = 4300 K and log g = 1.5. The elemental abundances were taken from Peterson et al. (1993), abundance of carbon log N (C) = -3.78.

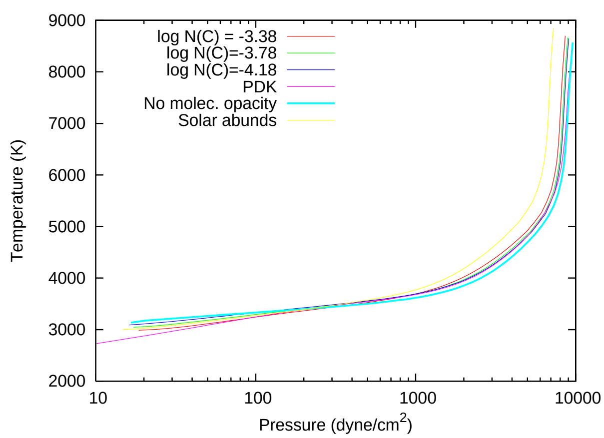

Figure 2: Temperature distributions in our model atmospheres of Arcturus computed for i) different carbon abundances, ii) solar chemical composition, iii) our model atmosphere computed taking into account only opacity in continuum and atomic lines, iv) the temperature distribution in the PDK model (Peterson at al. 1993).

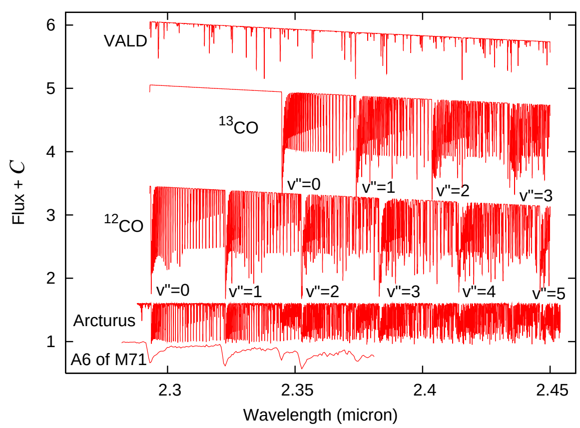

Figure 3: Identification of CO bands and atomic lines in the spectrum of Arcturus in the modelled wavelength range. For comparison, we show the observed spectra of Arcturus from Hinkle et al. (1995) and of the giant A6 in the globular cluster M71 (Pavlenko et al. 2003).

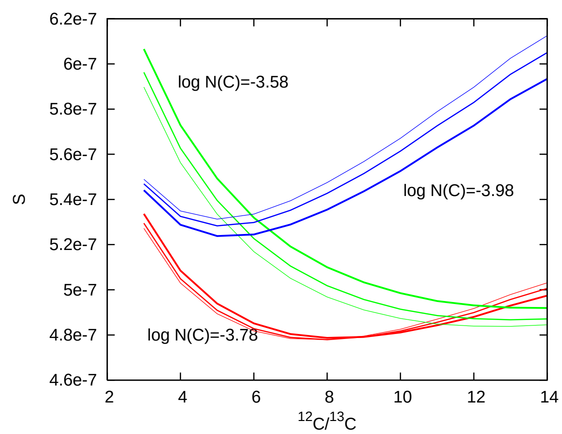

Figure 4: Minimum of $S = \Sigma(F_i^{obs} - F_i^{synt})$, here F_i^{obs} and F_i^{synt} are observed and computed fluxes, (see Pavlenko et al. 2003 for more detailed explanation) allows to determine the best values of ^{12}C/^{13}C and carbon abundance. In all cases, the effective temperature and gravity are Teff = 4300 K and log g = 1.5. The abundances of other elements are from Peterson et al. (1993).

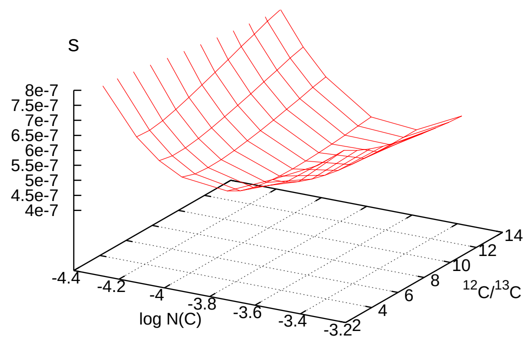

Figure 5: S values obtained from the fits of synthetic spectra computed for a series of model atmospheres of Teff = 4300 K and log g = 1.5 and different values of log N(C) and $^{12}C/^{13}C$ to the observed spectrum of Arcturus (Hinkle et al. 1995). The abundances of other elements were taken from Peterson et al.(1993).

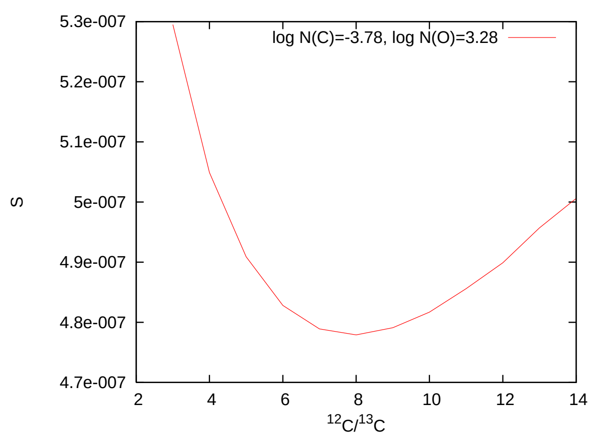

Figure 6: S vs. $^{12}C/^{13}C$ dependence provides the best-fit carbon isotope ratio ratio for Arcturus $^{12}C/^{13}C$ = 8 +/- 1. Abundance of carbon is log N(C) = -3.78.

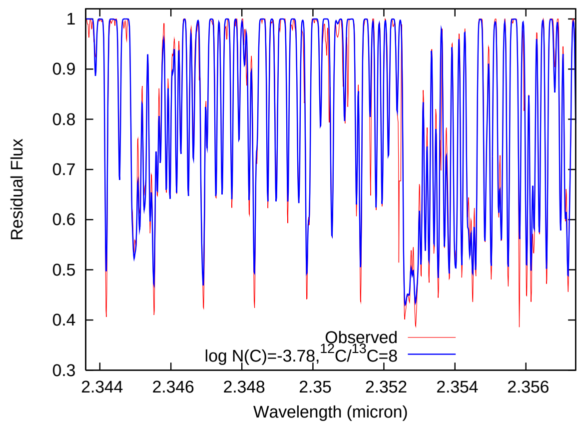

Figure 7: Fit of the computed spectrum for our model atmosphere with log N(C) = -3.78, log N(O) = -3.21, $^{12}C/^{13}C$ = 8 to the observed spectrum of Arcturus (Hinkle et al. 1995)

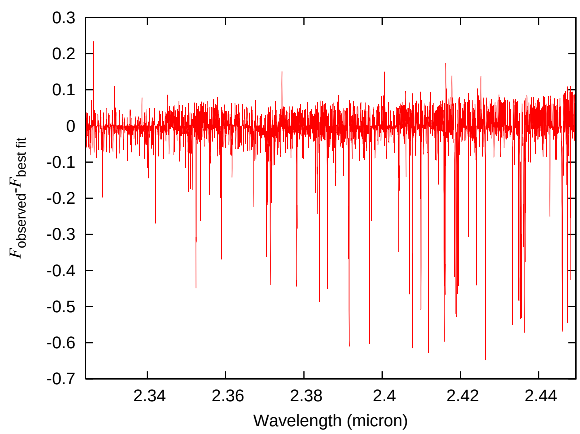

Figure 8: The difference between the observed and computed fluxes of Arcturus. Theoretical spectrum was computed for our model atmosphere of Teff = 4300 K and log g = 1.5 with log N(C) = -3.78, log N(O) = -3.21, and $^{12}C/^{13}C$ = 8. The other abundances are from Peterson et al. (1993).

References

[1] IAU 228 Symp. Proc. "From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution", held in Paris, France, May 23-27, 2005, eds V.Cill, P.Francois, F.Primas; Cambridge: Cambridge University Press, 1 (2005).

[2] Jr. I. Iben ApJ, **140**, 1631, (1964).

[3] E. Anders & N. Grevesse 1989, Geochimica et Cosmochimica Acta, **53**, 197 (1989).

[4] Jr.I. Iben, A. Renzini ARA&A, **21**, 271 (1983).

[5] C.Sneden, C.A. Pilachovski, D.A. VandenBerg ApJ, 311, 826 (1986).

[6] C.Charbonnel A&A, 282, 811 (1994).

[7] D.L.Lambert, L.M. Ries ApJ, **248**, 228 (1981).

[8] M.M. Briley, V.V. Smith, J. King, D.L. Lambert AJ, **113**, 306 (1997).

[9] K.K. Gilroy, J.A.Brown, ApJ, 371, 578 (1991).

[10] A.I. Boothroyd, I-J. Sackman ApJ, **510**, 232 (1999).

[11] Ya.V. Pavlenko, H. R. A. Jones, A. J. Longmore, 2003. MNRAS, 345, 311-324.

[12] http://simbad.u-strasbg.fr/Simbad

[13] D.E. Blackwell, A.D.Petford, R.B. Willis MNRAS, **221**, 427 (1986).

[14] G.C.Augason, B.J. Taylor, D.W.Strecher, E.F.Eriksson, f.C. Witteborn ApJ, **235**, 138 (1980)

[15] D.E. Blackwell, R.S.Ellis, P.A.Ibbetson, A.D.Petford, R.B. willis MNRAS, **171**, 425.

[16] A. Quirrenbach, D.Mozurkewich, D.F.Buscher, C.A. Hummel, J.T. Armstrong A&A, **312**, 160 (1996).

[17] R.E.M.Griffin, A.E.Lynas- Gray AJ, **117** 2998, (1999)

[18] B.M.Krupp BAAS, **5**, 336 (1973)

[19] R.F. Griffin, MNRAS, **167**, 645 (1974)

[20] Kopper, T. Sov. Astron.Lett.,, **3**, 247 (1977).

[21] L.Altas, Ap&SS, **134**, 85 (1987).

[22] R. Peterson, C.M.D Ore, R.Kurucz ApJ, 1993, 404, 333.

[23] T.R. Ayres, J.L.Linsky ApJ, **201**, 212 (1975).

[24] J.N.Heasley, S.T.Ridfway, D.F.Carbon, R.W.Milkey, D.N.B. Hall BAAS, **9**, 324 (1977).

[25] T.R. Ayres, H.W. Moos, J.L. Linsky ApJ, **248**, L137.

[26] N.Ryde, D.L. Lambert, M.J. Richter, J.H.Lacy ApJ, **580**, 447, (2002)

[27] G. Wiedemann, T,R. Ayres, D.E. Jennings, S.H. Saar ApJ, **423**, 806 (1994).

[28] C. Charbonnel, J.A. Brown, G.Wallerstein Astron. Astrophys. 1998 , **332**, 204.

[29] E.N.Gubbard, D.S.P. Dearborn ApJ, **239**, 249 (1980)

[30] P.C.Keenan, R.C.McNeil ApJS, **71**, 245 (1989).

[31] K.Hinkle, L. Wallace, W.Livingston PASP, **107**, 1402, (1995)

[32] Ya.V.Pavlenko, H.R.A.Jones, Yu. Lyubchik, J. Tennyson, D.J.Pinfield A&A, **447**, 709 (2006).

[33] Ya.V. Pavlenko 2003. Astron. Rept., 47, 59.

[34] Ya.V. Pavlenko 1997, Astrophys. Sci., **253**, 43 (1997).

[35] http://kurucz.harvard.edu

[36] 1993, CD ROM N 1-22, Cambridge, MA: Smithsonian Astrophysical Observatory.

[37] A.Borysow, In U.G.Jorgensen (ed.), Molecular Opacities in the Stellar Environment, Springer Verlag, 209.

[38] A.Borysow, U.G.Jorgensen, C.Zheng A&A, **324**, 185 (1997)

[39] Pavlenko, Ya., Zhukovskaya, S. KFNT, **19**, 28 (2003).

[40] M.J. Seaton Rev.Mex.Astron.Astrophys. **23**, 180 (1992).

[41] V.Tsymbal, ASPC, **108**, 198 (1996).

[42] C.R. Vidal, J.Cooper,E.W. Smith JQSRT, 10, 1011 (1970)

[43] V.P.Myerscough, M.R.C. McDowell MNRAS, **132**, 457 (1966).

[44] C. Sneden, H.R. Johnson, B.M. Krupp ApJ, **204**, 218 (1976).

[45] F. Kupka, N. Piskunov, T.A. Ryabchikova, H.C.Stempels, W.W.Weiss Astron. Astrophys. Suppl., 138, 119 (1999).

[46] A. Unsold 1995, Physics der Sternatmospharen, (Springer: Berlin)

[47] T. Tsuji Astron & Astrophys, **23**, 411 (1973).

[48] L.V. Gurvits et al. Thermodymamical properties of the individual substances. M., Nauka. (1982).

[49] D. Goorvitch 1994, Astrophys. J. Suppl., 95, 535.

[50] D.F. Gray The observation and analysis of stellar photospheres. New York, Wiley-Interscience, 484 p (1976).

[51] Ya.V. Pavlenko, L.A. Yakovina Astron. Reports, **38**, 768 (1994).

[52] Pavlenko, Ya.V., Jones, H.R.A. A&A, 397, 967 (2002).

[53] Ya.V.Pavlenko, T.R. Geballe, A.Evans, B. Smalley, S.P.S. Eyres, V.H.Tyne, L.A. Yakovina A&A, **417**, L39 (2004)

[54] Proc. of VIII Torino Workshop on Nucleosynthesis in AGB Stars "Constraints on AGB Nucleosynthesis from Observations" Granada, 5-10 February 2006, MemSAIt, **72**, 1002.